METHOD TO ROUGH SIZE COATED COMPONENTS FOR EASY ASSEMBLY

Technical Field

This invention is directed to coatings for machine components, and more particularly, to a method of applying conformable coatings to compressor components.

Background of the Invention

In a conventional screw machine, a male rotor and a female rotor, disposed in respective parallel overlapping bores defined within a rotor housing, coact to trap and compress volumes of gas. While two rotors are the most common design, three, or more, rotors may coact in pairs. The male and female rotors may differ in their lobe profiles and in the number of lobes and flutes. For example, the female rotor may have six lobes separated by six flutes, while the conjugate male rotor may have five lobes separated by five flutes. Accordingly, some or all possible combinations of lobe and flute coaction between the rotors occur on a cyclic basis. The coaction between the conjugate pairs of rotors is a combination of sliding and rolling contact which can produce different rates of wear. In addition to coacting in pairs, the rotors coact as well with the housing. Because a number of combinations of rotor contact takes place between conjugate pairs, the sealing/leakage between the various combinations may be different due to manufacturing tolerances and wear patterns. This can be the case even though manufacturing tolerances are held very tight with the attendant manufacturing costs and adequate lubrication or other liquid injection is provided for sealing.

The profile design of conjugate pairs of screw rotors must be provided with a clearance in most sections. The need to provide a clearance is the result of a number of factors including: thermal growth of the rotors as a result of gas being heated in the compression process; deflection of the rotors due to pressure loading resulting from the compression process; tolerances in the support bearing structure and machining tolerances on the rotors which may sometimes tend to locate the rotors too close to

one another which can lead to interference; and machining tolerances on the rotor profiles themselves which can also lead to interference. Superimposed upon these factors is the existence of pressure and thermal gradients as the pressure and temperature increase in going from suction to discharge.

The pressure gradient is normally in one direction during operation such that fluid pressure tends to force the rotors towards the suction side. The rotors are conventionally mounted in bearings at each end so as to provide both radial and axial restraint. The end clearance of the rotors at the discharge side is critical to sealing and the fluid pressure tends to force open the clearance.

There are certain sections of the rotor, such as the contact band, where zero clearance is maintained between the rotors. The segment of the rotor defining the contact band is the region where the required torque is transmitted between the rotors. The load between the rotors is different for a male rotor drive and for a female rotor drive. In a male drive the loading between the rotors may be equivalent to about 10% of the total compressor torque, whereas in the case of female rotor drive the loading between the rotors may be equivalent to about 90% of the total compressor torque. These segments are conventionally positioned near the pitch circles of the rotors which is the location of equal rotational speed on the rotors resulting in rolling contact and thereby in reduced or no sliding contact and thus less wear.

A substantial amount of end-running clearance must be maintained at the discharge end of screw compressors in order to prevent failure from rotor seizure. Seizure results when the discharge end of the rotor contacts the compressor end casing during operation and may be caused by the thermal expansion of the rotor or by the intermittent contacts between the rotors and the end casing due to, for example, pressure pulsations in the compression process.

Summary of the Invention

It is an object of this invention to provide an improved method for applying coatings to components of a screw machine to reduce leakage in the screw machine.

It is another object of this invention to provide a method for rough coating screw machine component parts as a first step in applying a coating to screw machine components.

It is an additional object of this invention to ease assembly of screw machine components through obtaining a more uniform surface coating by using an initial rough coat application method and applying a smoothing step prior to assembly.

Still another object of this invention is to reduce excessive and uneven thickness of component coatings to ease component assembly.

These objects, and others as will become apparent hereinafter, are accomplished by the present invention.

In accordance with the present invention, a method for applying a coating to one or more portions of the screw rotors and/or the inner bore surfaces of the housing is provided.

The foregoing objects and following advantages are achieved by the method of the present invention for coating surfaces of a screw machine. The method comprises the steps of providing at least one of a plurality of screw machine components including a rotor housing having at least a pair of parallel, overlapping bores; a conjugate set of intermeshing rotors located in the bores, wherein each of the rotors has helical lobes having radially outward tip portions and intervening radially inward root portions; rough coating a surface of at least one of the plurality of components with a conformable coating, wherein the coating is substantially applied to the surface and has variable or excessive thickness over the surface; and leveling the conformable

coating to a substantially uniform thickness prior to final assembly of the plurality of components, the substantially uniform thickness selected to ease assembly of the components, while maintaining coating performance criteria.

Brief Description of the Drawings

For a fuller understanding of the present invention, reference should now be made to the following detailed description of various embodiments thereof taken in conjunction with the accompanying drawings wherein:

Figure 1 is a transverse section through a screw machine;

Figure 2 is a partially sectioned view of the screw machine of Figure 1;

Figure 3 is an enlarged view of a portion of the discharge end of the screw machine of Figure 1;

Figure 4 is an enlarged portion of Figure 1 with the various coatings of the present invention illustrated;

Figure 5 is a partially sectioned view showing a DLC coating on the rotor ends;

Figure 6 is a partially sectioned view showing a DLC coating on the on the discharge casing; and

Figure 7 is a partially sectioned view showing a DLC coated disc;

Figure 8 is an enlarged view of a DLC coating;

Figure 9 is a perspective view of an axial section of the rotor pair of Figure 1.

Figure 10 is a schematic representation of a coating prior to the coating smoothing process of the present invention, and a sizing device for smoothing the coating.

Figure 11 is a schematic representation of the component after application of the rough coat smoothing method shown in Figure 10.

Figure 12 is a further embodiment of a method for achieving the results shown in Figure 11, having specific application to rotors, such that an uncoated rotor is used to smooth a coated rotor.

Description of the Preferred Embodiments

In Figure 1, there is depicted a screw machine 10, such as a screw compressor, having a rotor housing or casing 12 with overlapping bores 12-1 and 12-2 located therein. Female rotor 14 having a pitch circle, P_F, is located in bore 12-1. Male rotor 16 having a pitch circle, P_M, is located in bore 12-2. The parallel axes indicated by points A and B are perpendicular to the plane of Figure 1 and separated by a distance equal to the sum of the radius, R_F, of the pitch circle, P_F, of female rotor 14 and the pitch radius, R_M, of the pitch circle, P_M, of male rotor 16. The axis indicated by point A is the axis of rotation of female rotor 14 and generally of the center of bore 12-1 whose diameter generally corresponds to the diameter of the tip circle, T_F, of female rotor 14. Similarly, the axis indicated by point B is the axis of rotation of male rotor 16 and generally of the center of bore 12-2 whose diameter generally corresponds to the diameter of the tip circle, T_M, of male rotor 16. Typically, the rotor and the bore centerlines are offset by a very small amount to compensate for clearance and deflection. Neglecting operating clearances, the extension of the bore 12-1 through the overlapping portion with bore 12-2 will intersect line A-B at the tangent point with the root circle, R_{MR}, of male rotor 16. Similarly, the extension of the bore 12-2 through the overlapping portion with bore 12-1 will intersect line A-B at the tangent point with the root circle, R_{FR}, of female rotor 14 and this common point is labeled F_1 relative to female rotor 14 and M_1 relative to male rotor 16.

In the illustrated embodiments, female rotor 14 has six lands or tips, 14-1, separated by six grooves or flutes, 14-2, while male rotor 16 has five lands or tips, 16-1, separated by five grooves or flutes 16-2. Accordingly, the rotational speed of rotor 16 will be 6/5 or 120% of that of rotor 14. Either the female rotor 14 or the male rotor 16 may be connected to a prime mover (not illustrated) and serve as the driving rotor. Other combinations of the number of female and male lands and grooves may also be used.

Referring now to Figures 2 and 3, rotor 14 has a shaft portion 14-3 with a shoulder 14-4 formed between shaft portion 14-3 and rotor 14. Shaft portion 14-3 of rotor 14 is supported in outlet or discharge casing 13 by one, or more, bearing(s) 30. Similarly, rotor 16 has a shaft portion 16-3 with a shoulder 16-4 formed between shaft portion 16-3 and rotor 16. Shaft portion 16-3 of rotor 16 is supported in outlet casing 13 by one, or more bearing(s) 31. Suction side shaft portions 14-5 and 16-5 of rotors 14 and 16, respectively, are supportingly received in rotor housing 12 by roller bearings 32 and 33, respectively.

In operation, as a refrigerant compressor, assuming male rotor 16 to be the driving rotor, rotor 16 rotates engaging rotor 14 and causing its rotation. The coaction of rotating rotors 16 and 14, disposed within the respective bores 12-2 and 12-1, draws refrigerant gas via suction inlet 18 into the grooves of rotors 16 and 14 which engage to trap and compress volumes of gas and deliver the hot compressed gas to discharge port 19. The trapped gas acting on rotors 14 and 16, which are movable, tends to separate discharge ends 14-4 and 16-4 from outlet casing surface 13-1 to create/increase the leak passage. Movement of rotors 14 and 16 away from outlet casing surface 13-1 results in movement of rotors 14 and 16 towards or into engagement with surface 12-3 of rotor casing 12 by shoulders 14-6 and 16-6, respectively. In addition to the leak path between rotor shoulders 14-4 and 16-4 and outlet casing surface 13-1, leakage can occur across the line contact between rotors 14 and 16 as well as between the tips of lands 14-1 and 16-1, respectively, and bores 12-1 and 12-2, respectively. The leakage across the lands/line contact can be reduced by

the use of oil for sealing but the oil generates a viscous drag loss between the moving parts and must be removed from the discharge gas.

As noted hereinbefore, the contact band is defined by zero clearance rather than by location. Figure 4 shows an enlarged portion of Figure 1 in order to illustrate the relocation of the contact band in accordance with one aspect of the present invention. Referring to FIG. 1, the contact band would be located inside of the pitch circle, P_F, of female rotor 14 which is in the region of the female tip 14-1 and outside of the pitch circle, P_M, of male rotor 16 which is in the region of the male root 16-2.

For an oil-free or reduced oil compressor, the rotor tips must be brought as close as possible to the rotor housing bores 12-1 and 12-2 in order to reduce the leakage since oil cannot be used for sealing. The wear and power loss due to the friction between the rotor tips and the housing will be excessive if contact occurs between the rotors and housing. Even where the rotors are lubricated, there can be leakage across the oil seal and the oil must be removed from the refrigerant to minimize its circulation through the refrigeration system with its deterioration of the heat transfer efficiency as well as to maintain the necessary oil for lubrication in the compressor.

Accordingly, a low friction, wear resistant coating is deposited on the tips or lands 14-1 and 16-1 of the rotors 14 and 16, respectively. One suitable low friction, wear resistant coating is a low friction diamond-like-carbon (DLC) coating of the type used locally on the tip surface of the vane in a rotary compressor as disclosed in commonly assigned U.S. Patent No. 5,672,054. Such a the DLC coating serves to overcome lubrication difficulties associated with the use of new oil and refrigerant combinations. The DLC coating is both lubricous and also wear resistant in that, as discussed in detail in U.S. Patent 5,672,054, the entire disclosure of which is hereby incorporated by reference, it is made up of alternating layers of a hard material, such as tungsten carbide, and amorphous carbon.

Examples of other suitable low friction, wear resistant coatings include titanium nitride and other single material, single layer nitride coatings, as well as carbide and

ceramic coatings having both high wear resistance and a low coefficient of friction. The presence of a low friction, wear resistant coating on the tips or in the valleys of lands of the respective rotors provides several advantages. First, oil free or reduced oil operation relative to the rotors is possible without excessive wear or friction. Second, machining tolerances can be relaxed because some contact with the rotor bores can be tolerated. Third, the need for oil sealing between the rotors and the rotor bores can be reduced or eliminated because of the possibility of running with less clearance between the rotor tips or lands 14-1 and 16-1 and rotor bores 12-1 and 12-2, respectively.

Because the contact band on female rotor 14 is located near the tip, a single DLC coating can be used to cover both areas of interest on the female rotor due to their narrow spacing, or overlap, depending upon the rotor profiles. The single DLC coating 40 on the female rotor is preferred for ease of manufacture as illustrated on Figure 4. The portion 40-1 of coating 40 corresponds to the contact band and the portion 40-2 corresponds to the portion of tip or land 14-2 that comes closest to bore 12-1. The corresponding DLC coatings on male rotor 16 are more widely separated with the coating 60 deposited on the rotor tips and the coating 61 deposited near the root portion corresponding to the contact band.

Like the rotor tips, the rotor ends are run with a clearance that constitutes a leak path. In accordance with a further aspect of the present invention, a DLC coating may be applied at the discharge end faces of the rotors, at the facing surfaces of the discharge casing 13 or on a coated insert disposed between the rotors and the discharge casing 13, whereby the running clearance, and thereby the leakage path, is reduced. Referring now to Figure 5, a DLC coating is applied to the discharge end of the rotors 14 and 16. Specifically, DLC coating 42 is applied to the discharge end of female rotor 14 and DLC coating 62 is applied to the discharge end of male rotor 16. Because the DLC coatings 42 and 62 can accommodate some contact with outlet casing surface 13-1, a reduced end running clearance can be employed with reduced leakage. Referring now to Figure 6, the DLC coating 82 is applied to the casing surface 13-1 rather than to the ends of the rotors 14 and 16, as in the Figure 5

embodiment. In the Figure 7 embodiment, a separate member 90 is located between the ends of rotors 14 and 16 and casing surface 13-1. Because the member 90 conforms to the cross section of bores 12-1 and 12-2 or is otherwise restrained from motion relative to casing surface 13-1, it is not capable of rotation and the relative movement will be between member 90 and the discharge ends of rotors 14 and 16. Accordingly, only the surface of member 90 facing rotors 14 and 16 needs to be provided with a DLC coating 92. In the embodiments of Figures 5-7 a DLC coating is located between the ends of rotors 14 and 16 and surface 13-1 such that its lubricity will protect the rotors and casing from wear during an occasional contact thereby permitting the closing of the end running clearance and narrowing the leakage path.

Referring now to Figure 8, a greatly exaggerated cross section typical of coatings 40, 42, 60, 61, 62, 82 and 92 is illustrated although it is labeled 40. DLC coating 40 is made up of hard bilayers 40' and lubricious bilayers 40". The range of bilayer thickness is 1 to 20nm, with the preferred range being between 5 and 10nm. In addition to wear resistant coatings, a conformable coating, which may be abradable or extrudable into shape, may be applied to the rotors 14 and 16, rotor shoulders 14-4 and/or 16-4, casing surface 13-1, and/or to the bores 12-1 and 12-2. While the entire rotors and bores may be coated, a localized coating in the rotor flutes or valleys 14-2 and 16-2, respectively, as illustrated in Figure 9, provides essentially all of the benefits relative to the coaction between the rotors. Although the contact band is a no clearance area and requires precise machining, the tolerances can be relaxed relative to the coaction between the remainder of the rotor lobe profiles. Additionally, the conformable coating of the bores 12-1 and 12-2 accommodates the flexure of the rotors 14 and 16 during actual operation to maintain the sealing function. Referring to Figures 4 and 9, the female rotor valleys may be provided with conformable coating 44 and the male rotor valley may be provided with conformable coating 64. Additionally, bores 12-1 and 12-2 may be provided with conformable coating 84.

Various plastically conformable coatings may be used including, for example, iron phosphate, magnesium phosphate, nickel polymer amalgams, nickel zinc alloys, aluminum silicon alloys with polyester, and aluminum silicon alloys with

polymethylmetacrylate (PMMA). Also, conventional coatings methods, including for example thermal spraying, physical vapor deposition (PVD), chemical vapor deposition (CVD), or any suitable aqueous deposition, may be used to treat the surfaces of the screw machine of the present invention.

The preferred method for the present invention of applying the conformable coatings described on the components indicated is through a rough coating and sizing or leveling technique, as shown in FIG. 10.

In accordance with this method, the conformable coating, generally referred to as conformable coating 100, which is intended to include all coatings referenced herein, is roughly applied to the component 102 surface, such that it's cross section shows a excess amount of coating 100 on the component. The conformable coating 100 is roughly applied such that the minimum amount at any one place substantially meets the minimum coating performance requirements of the assembly. Surface 102 can be any component surface described herein as receiving a conformable coating. The conformable coating is typically applied is shown in Figure 10 with peaks and valleys which, in the prior art, when not removed or leveled, cause assembly difficulties due to the interference between components as caused by such surface irregularities. Accordingly, the existence of surface irregularities such as peaks cause mating or interacting components to have interference fits as opposed to the desired meshing, such as with screw rotors.

Alternately, the coating may be applied with substantially uniform thickness, but said thickness may vary from component to component due to normal process variations. In this case the range of allowable thicknesses may be chosen so the minimum normally occurring thickness meets the minimum coating performance requirements of the assembly. In this case a typical coated component will have excess thickness which can cause assembly difficulties due to the interference between components.

In accordance with one embodiment of the present invention, prior to assembling mating or interacting parts, the coating on the parts are first smoothed with a sizing

device, such as a rod or plate, or similar device 104, which removes excess coating material and smoothes the surface to a desired minimum thickness and texture, as required by the machine's performance criteria. The sizing device is preferably moved steadily adjacent to the component surface until the entire surface is smoothed and leveled as shown in Figure 11. For shapes such as cylinders or spheres other devices having conforming shapes can be passed over the coating for removal and smoothing of the surface.

In another embodiment, as shown in Figure 12, and having specific application to mating or interactive components such as screw compressor rotors, the actual mating component to the newly coated component is used to achieve the smoothing process. Accordingly, one component 102, and for instance a screw rotor of a screw compressor, is rough coated with a conformable coating. It's mating screw rotor 104, uncoated or having been finished coated through this process, is then moved in to place in mating alignment with the coated screw compressor, and moved relative the coated screw compressor, wherein the mating rotor functions to remove excess peaks and smooth valleys forming an evenly coated mating rotor. If the mating, leveling component has not already been coated, the mating, leveling component must be held at a predetermined optimal distance for achieving the desired coating thickness on the other component. The mating, leveling component may be a master fixture, that is it may be a permanent tool used to size any number of rotors 102 to fit up with their respective rotors 104.

Although the present invention has been specifically illustrated and described in terms of a twin rotor screw machine, it is applicable to screw machines employing three or more rotors. It is therefore intended that the present invention is to be limited only by the scope of the appended claims.